

WATER EXTRACTION FROM COAL-FIRED POWER PLANT FLUE GAS

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ABSTRACT

This quarterly report lists activities performed for the subject project. The project is divided into ten tasks. Task 1 was completed in the first quarter and consisted of evaluating desiccant materials to test in Task 2. The outcome of Task 1 was the selection of three desiccants to test in Task 2. Task 2 consisted of desiccant testing in a small-scale combustion test furnace at the Energy & Environmental Research Center. Task 2 bench-scale testing of the desiccant performance under actual combustion conditions was completed in Quarter 2. Two fuels, a Powder River Basin coal and natural gas, were tested with the three desiccants. All of the desiccants performed as expected regarding their ability to absorb moisture from the flue gas. In this quarter Task 3 was completed. Task 3 was to prepare a preliminary test plan for the pilot-scale tests, which was constructed and delivered to the U.S. Department of Energy as a topical report. Task 4 was also completed in this quarter. Task 4 was to develop a system design for pilot-scale tests. Task 5 was initiated and is to procure equipment and parts for construction of the pilot-scale system.

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EXECUTIVE SUMMARY

The goals of this project are to develop technology for recovering water from combustion flue gas to reduce the net water requirements of power plants burning fossil fuels and to perform an engineering evaluation to determine how such technology can be integrated into various power-generating systems, including steam turbine and combined-cycle plants. In the past, power plants burning fossil fuels were designed to generate electricity at least cost under circumstances of abundant coal and natural gas resources and adequate supplies of water for plant cooling. Future plants will need to be designed and operated to conserve both fuel and water. Water is becoming scarce and expensive in many parts of the United States including California, where strong economic incentive exists to reduce the net cooling water requirements of power plant subsystems cooling steam turbine condensers and scrubbing stack gases.

Future escalation in the price of natural gas and possible restrictions on carbon emissions from fossil fuels will likewise provide a strong incentive for increasing generating efficiencies. Coal utilization would be most severely impacted by climate change policy initiatives because a coal-fired steam plant emits nearly three times more CO₂ than a natural gas-fired combined-cycle plant with similar generating capacity. Issues of heat and mass transfer concerning water recovery, plant efficiency, and emissions are all related, so technical options for recovering water will open up new opportunities for improving performance relating to the other two factors.

The project is divided into ten tasks as follows:

- Task 1. Desiccant Selection
- Task 2. Desiccant Laboratory Test Evaluation
- Task 3. Test Plan Development
- Task 4. Test Facility and Equipment Design
- Task 5. Equipment and Materials Procurement
- Task 6. Test Equipment Installation
- Task 7. Testing
- Task 8. Test Data Evaluation
- Task 9. Commercial Power Plant Evaluation
- Task 10. Program Management

In the first quarter of the project, a kickoff meeting was held at the University of North Dakota (UND) Energy & Environmental Research Center (EERC) on November 6, 2003. Attendees were Ms. Barbara Carney of the Department of Energy (DOE) National Energy Technology Laboratory (NETL) and Dr. Bruce Folkedahl, Dr. Michael Jones, Mr. Greg Weber, and Dr. Everett Sondreal, all of UND EERC. Attendees from Siemens Westinghouse Power Corporation (SWPC) were Mr. Lloyd Dean, Mr. Phil Deen, Mr. Dick Newby, and Mr. Eric Weinstein.

Communication protocols for the project were developed, along with a formalized statement of project responsibilities for each of the tasks listed above.

In the second quarter, Task 2 was completed. In Task 1, three desiccants were selected for further analysis in Task 2. Task 2 consisted of desiccant testing in a small-scale combustion test furnace at the EERC. Task 2 bench-scale testing of the desiccant performance under actual combustion conditions was completed this quarter. Two fuels, a Powder River Basin coal and natural gas, were tested with the three desiccants. All of the desiccants performed as expected regarding their ability to absorb moisture from the flue gas. Precipitates formed in the last samples taken from two of the desiccants tested with the coal flue gas. These precipitates were analyzed and found to consist of sulfates, carbonates, and coal combustion ash.

In the current quarter, a preliminary test plan was constructed for the pilot-scale tests to be initiated in September of this year. They are preliminary and will change slightly when the entire system has been completed. The preliminary test plan was delivered to DOE, and a second revised plan will be submitted approximately 2 weeks prior to the beginning of the first pilot-scale test. The system design was also completed this quarter. A copy of the design was sent to the DOE. Based on this design, equipment and construction components have been ordered. Completion of construction is scheduled for the middle of September of this year.

WATER EXTRACTION FROM COAL-FIRED POWER PLANT FLUE GAS

INTRODUCTION AND BACKGROUND

The goals of this project are to develop technology for recovering water from combustion flue gas to reduce the net water requirements of power plants burning fossil fuels and to perform an engineering evaluation to determine how such technology can be integrated into various power-generating systems, including steam turbine and combined-cycle plants. An ancillary objective of the engineering evaluation is to identify opportunities for integrating water recovery in ways that improve efficiency and reduce emissions of acid gases and carbon dioxide. Power plants burning fossil fuels have in the past been designed to generate electricity at least cost under circumstances of abundant coal and natural gas resources and adequate supplies of water for plant cooling. Future plants will increasingly need to be designed and operated to conserve both fuel and water. Water is becoming scarce and expensive in many parts of the United States including California, where a strong economic incentive exists to reduce the net cooling water requirements of power plant subsystems cooling steam turbine condensers and scrubbing stack gases.

Future escalation in the price of natural gas and possible restrictions on carbon emissions from fossil fuels will likewise provide a strong incentive for increasing generating efficiencies. Coal utilization would be most severely impacted by climate change policy initiatives because a coal-fired steam plant emits nearly three times more CO₂ than a natural gas-fired combined cycle plant with similar generating capacity. Issues of heat and mass transfer concerning water recovery, plant efficiency, and emissions are all related, so technical options for recovering water will open up new opportunities for improving performance relating to the other two factors. The amount of water that can be recovered from flue gas is sufficient to substantially reduce, and in some cases eliminate, the need for off-plant sources of water. The work in this project will demonstrate proof of concept for a desiccant technology that is based on innovative adaptation of established principles used in absorption refrigeration. This technology is likely to find an immediate market among plants in water-scarce areas. It could also provide added value through integration with other plant systems. Condensing water from flue gas may provide opportunities for removing SO₂ and NO_x, approaching near-zero emissions of acid gases.

Coal-fired power plants require access to outside water sources for several aspects of their operation, in addition to steam cycle condensation and process cooling needs. In integrated gasification combined-cycle (IGCC) systems, significant water is used in the coal gasification process and for syngas saturation; this water is lost through the power plant stack. In pulverized coal (pc) power plants, water inherent in the coal as well as water associated with flue gas scrubbing is lost through the stack. The strategy used to reduce water consumption in areas where water restrictions are stringent is to employ an air-cooled condenser, as opposed to once-through cooling or a cooling tower. However, even plants with air-cooled condensers to minimize water consumption require a significant amount of water in several cases in order to allow for required steam drum blowdown, power augmentation systems, and gas turbine inlet evaporative cooling or fogging systems. There is no practiced method of extracting the usually abundant water found in the power plant stack gas. Some work has been done on mechanical

heat rejection to condense water vapor. Such systems would require massive and expensive heat rejection equipment, would be severely limited by high ambient temperatures, and would result in decreased gas turbine performance as a result of higher back pressure due to closed heat exchangers in the flow path. The process being investigated in this project uses liquid desiccant-based dehumidification technology to efficiently extract water from the power plant flue gas, requires minimal heat rejection equipment, can function across the entire ambient range, and results in only a small increase in exhaust pressure.

The advantage of using a desiccant is that it facilitates the recovery of useful amounts of water at flue gas temperatures that can be reasonably achieved during power plant operation. Direct-contact cooling with a desiccant solution can be engineered to minimize pressure drop, and any water evaporating into the flue gas from an upstream scrubber would be recovered for reuse. The alternative of indirect cooling in an air/flue gas-condensing heat exchanger without a desiccant, which would be limited to applications involving low ambient temperatures, raises significant engineering and economic problems involved with the size and cost of the heat exchanger, pressure drop, corrosion, fouling, and discharge of nonbuoyant stack gas.

This project is a 2-year program to demonstrate the feasibility and merits of a liquid desiccant-based process that will efficiently and economically remove water vapor from the flue gas of coal-fired power plants (IGCC and pc steam plants) and recycle it for in-plant use or export it for clean water conservation. Reduction of water consumption by power plants is quickly becoming a significant issue when attempting to obtain permits for power plants and when required to meet new, more restrictive water consumption allowances being considered by the U.S. Environmental Protection Agency under proposed Rule 316b.

EXPERIMENTAL

Task 1 was an investigation of the potential viability of various desiccants to meet performance requirements in this application. The selection of a desiccant for the proposed system hinged on several criteria. These criteria were identified, applicable chemical/ physical/ environmental/cost data gathered, and the data compared. A weighted ranking system based on a criteria list was developed for use in the evaluation and comparison of the candidate desiccants. Three candidate desiccants were chosen for further testing in a bench-scale system. The final candidate desiccant selection will promote a flue gas dehydration process that complies with environmental regulations and results in optimal performance.

In the second quarter, Task 2 was completed. The objective of this task was to test the candidate desiccants selected in Task 1 using the Energy & Environmental Research Center's (EERC's) conversion and environmental process simulator (CEPS). Based in part on the results of this testing, a final desiccant will be selected. This selected desiccant will then be used in the larger pilot-scale Water Extraction from Turbine Exhaust (WETEX) demonstration using the EERC's slagging furnace system as a flue gas source.

The three desiccants chosen in Task 1 were evaluated in Task 2 under identical bench-scale conditions to ascertain which desiccant would be the most appropriate one to take forward to the

next phase of pilot-scale testing and then into full-scale demonstration. All three desiccants chosen have unique beneficial qualities as well as challenges to overcome.

RESULTS AND DISCUSSION

In the first quarter, Task 1 was completed. This task consisted of evaluating multiple desiccants for use in this application. The specific criteria used to evaluate the desiccants were as follows:

- Adverse impact of the flue gas constituents on the desiccant
- Maintenance frequency/complexity cost
- Parts replacement
- Desiccant makeup
- Material handling
- Impact of desiccant on system operation and cost
- Flow characteristics when in solution
- Amount of available property data
- Permeability
- Solubility limits
- Removal of combustion products other than water
- Desiccant capital cost
- Heat transfer properties
- Corrosiveness
- Ability of desiccant to remove water from the exhaust stream
- Environmental effects of desiccant slip

The review of the available information on desiccants in conjunction with the weighting scheme led to the selection of three desiccants to be tested in the EERC CEPS. Two of the desiccants chosen for further evaluation have potential corrosion issues. Additives used in industry to reduce the corrosivity of these desiccants were investigated, but it was determined they would be ineffective in this application. Of the three desiccants chosen, one is an organic desiccant, and two are inorganic desiccants.

In the second quarter, bench-scale tests were performed to evaluate the performance of the selected desiccants under combustion flue gas conditions. A Powder River Basin (PRB) subbituminous coal was used as the solid fuel with identical tests performed using natural gas fuel to produce flue gas. The desiccant materials all performed as expected with respect to the amount of moisture removed from the flue gas stream of both the natural gas and coal combustion tests: the lower the vapor pressure of the desiccant, the more moisture it removed from the flue gas stream.

In the third quarter, a preliminary test plan was developed to lay out the series of operating conditions and schedule for the pilot-scale test that will start at the end of September 2004. The test plan will be revised approximately 2 weeks prior to the start of the test to reflect any changes in construction of the system and or other unforeseen barriers to preferred process conditions.

Because the test plan and the system design contain process conditions and system components that are proprietary they will not be detailed here. Documents detailing these two activities have been sent under separate cover to the DOE.

CONCLUSIONS

Work on this project is proceeding as scheduled. A kickoff meeting was held, and the project communication protocols established among team members. The project is divided into ten tasks. Task 1, completed the first quarter, was the review and selection of desiccants for testing in Task 2. Three desiccants were chosen for further evaluation in Task 2, which was completed in the second quarter. This task consisted of physical testing of the desiccants in contact with combustion flue gas in a small-scale combustion system. Two fuels, a PRB coal and natural gas, were used to produce combustion gas in these tests. The three desiccants chosen in Task 1 were tested in the small-scale combustor absorber system. All of the desiccants performed as expected regarding their ability to absorb moisture from the flue gas. The duration of the tests for each desiccant and fuel combination was 3 hours, and no significant interactions between the inorganic flue gas constituents and the desiccants were found during the tests. Precipitates did form for two of the desiccants upon cooling. The precipitates were analyzed and found to consist of carbonates, sulfates, and coal combustion ash material. In this quarter, a test plan was formulated and delivered to the DOE as a topical report for Task 3. Additionally, a system design was developed and also submitted under separate cover to the DOE. All major system components have been ordered, and construction is scheduled to begin in July of 2004.